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Optimization of Keyboard Design for Specialized Text Entry (Reprint)

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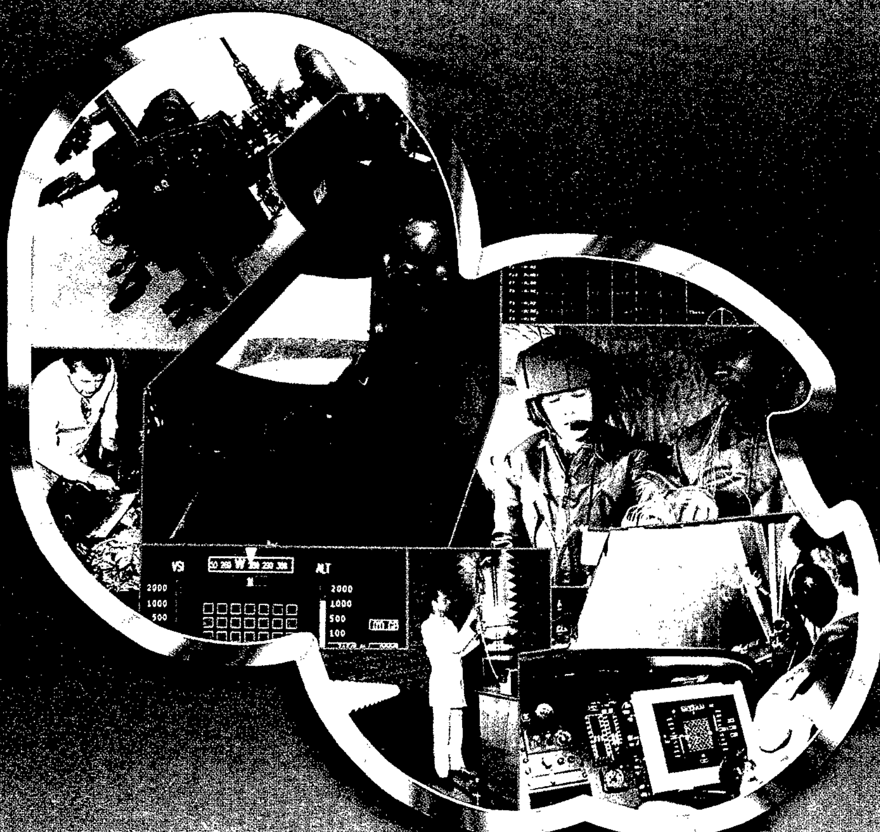

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As computers are introduced into ever more devices with new methods of inputting information, there has been interest in how to optimally design the information input system. We build on previous work along these lines to demonstrate a program that can quickly build the optimal keyboard layout that minimizes the time required to input a given set of data. This approach makes it possible to create different keyboard designs for different specialized uses of keyboards and/or for different individuals. In our report we outline the basic approach to the optimization process, identify situations where such optimization could be beneficial, and demonstrate the effectiveness of the optimization.

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OPTIMIZATION OF KEYBOARD DESIGN FOR SPECIALIZED TEXT ENTRY

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ABSTRACT
As computers are introduced into ever more devices with new methods of inputting information, there has been interest in how to optimally design the information input system. We build on previous work along these lines to demonstrate a program that can quickly build the optimal keyboard layout that minimizes the time required to input a given set of data. This approach makes it possible to create different keyboard designs for different specialized uses of keyboards and/or for different individuals. In our report we outline the basic approach to the optimization process, identify situations where such optimization could be beneficial, and demonstrate the effectiveness of the optimization.

INTRODUCTION
Easily entering information into computers has been recognized as a key obstacle to adoption of computers for a variety of uses. Despite improvements in voice and handwriting recognition, the alphabet keyboard remains one of the best technologies for entering a large variety of information accurately and quickly. However, the standard ten-finger keyboard that dominates information input on desktop and laptop computers is not practical for a variety of new situations. Thus, a key issue is how to design alternative keyboards that can be used in these new situations.

For example, many U. S. Army military helicopters now include computers that process and display a variety of information. A keyboard is provided for crewmembers to enter various sorts of information. The current keyboard has letters arranged alphabetically, which offers some benefits in terms of foreknowledge of where letters will be located, but probably is not optimized with regard to entering information as quickly as possible.

Another situation familiar to many people is the design of keyboards for entering text information into personal digital assistants and mobile phones. Early designs replicated the QWERTY keyboard commonly used for ten-finger typing, but required the user to press individual letters with a stylus pen. It was soon recognized that the QWERTY keyboard design was not well suited to "one-finger" typing, and alternative keyboard designs appeared that were optimized for one-finger data entry. Some examples of alternative designs include FITALY (Textware Solutions, 1998); OPTI (MacKenzie & Zhang, 1999), and ATOMIK (Zhai, Hunter, & Smith, 2002).

Many of these new designs are based on optimization strategies. The FITALY keyboard was designed, among other things, to minimize the time required to enter text. It achieved this through consideration of the frequency of using individual letters and the frequency of letter-to-letter transitions. Letters that were commonly paired together in text were placed close to each other. Likewise, the ATOMIK keyboard was created by an optimization algorithm that minimized the time required to move between pairs of letters (using Fitts' (1954) law as an estimate of movement time). Zhai et al. (2002) includes an excellent discussion of using optimization techniques for keyboard design.

The benefits of an optimized design necessarily depend on the validity of the optimizing factors. A keyboard optimized for one-finger entry will probably have a poor design if people actually use two

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or three fingers to enter text. More generally, the design of the keyboard needs to consider how the keyboard will be used. In some situations, Fitts' law is very appropriate; but in other situations, Fitts' law may not apply or may not be the most important factor. It would be useful to be able to create keyboard designs that are optimized relative to factors other than Fitts' law.

Along similar lines, a one-finger entry system that is optimized with respect to the frequency of letter pairs is valid only if the underlying frequencies accurately represent the data being entered by users. It seems very likely that helicopter pilots would enter data that have different frequencies of letter pairs than what is reported in standard tables (e.g., Mayzner & Tresselt, 1965). It would be useful to be able to create keyboard designs that are optimized relative to a particular corpus of textual data.

OPTIMIZED DESIGNS FOR SPECIALIZED SITUATIONS

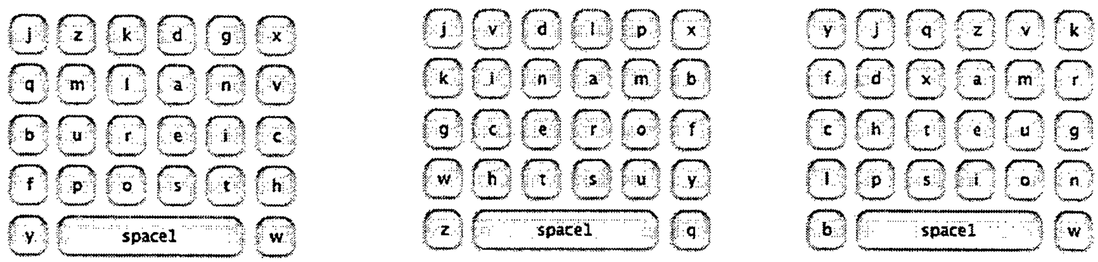
We have created a software program, called KeyboardTool, that can create optimized keyboard designs relative to a variety of movement time calculations and for any specified text corpus. The program is derived from an earlier program called MFDTool that creates optimized multifunction displays (MFDs) (Francis, 1999; Francis & Rash, 2002). Data entry keyboards are MFDs with a hierarchy of information that is only one level deep. These programs make it easy for anyone to apply and modify the optimization approaches used in the creation of the FITALY and ATOMIK keyboards.

The design of an optimized keyboard with KeyboardTool requires four types of information. First, the physical arrangement and size of buttons must be specified. This is done with a graphical user interface in the KeyboardTool program. Second, the labels for the keys must be identified. For a keyboard, the labels include the letters of the alphabet and perhaps numbers and other symbol characters. Third, the time required to move between every pair of buttons must be given. KeyboardTool provides calculations of a variety of movement times (including one based on Fitts' law), but also accepts other calculations. Fourth, a corpus of text must be provided. For the provided physical arrangement of the keys and labels, KeyboardTool will find a design that minimizes the given movement time that will be required to enter the corpus of text. Other constraints can also be imposed on the optimization process. For example, in all of the designs discussed below, the space label was fixed to a large button. The optimization then worked around this constraint.

Figure 1a shows a keyboard design that has been optimized for entering the text given in the HFES call for papers (http://hfes.org/meetings/2003menu.html). The movement time between each pair of keys has been estimated with Fitts' law, under the assumption of a person using a stylus or one-finger typing approach. KeyboardTool predicts that it would take a person approximately 2.6 minutes to enter the given text. (This is actually a lower bound, as it assumes making no mistakes and moving directly from one key to the next.)

Figure 1b shows an alternative keyboard design that has been optimized for a different text corpus: the front page of the U. S. Army Aeromedical Research Laboratory, USAARL, web site (http://www.usaarl.army.mil/).

Figure 1c shows still another alternative keyboard design that has been optimized for the HFES call for papers text corpus, but uses a different calculation for movement time that hypothesizes problems when the hand occludes some keys. If a finger or stylus is being used to press the key on the upper left, then the (right) hand will cover some of the keys along the lower right. Such occlusion may result in a longer time needed to move to occluded keys. We assumed that such occlusion resulted in a movement time of 1.5 seconds (as the user lifted their hand and then moved directly to the desired key). This may not be an accurate estimate, but it demonstrates the basic issue.



a b C

Figure 1. Three different optimized keyboard designs. In (a) the keyboard was optimized for entering text from the HFES call for papers. In (b) the keyboard was optimized for entering text from the USAARL web page. In (c) the keyboard was optimized for the HFES call for papers, but with a calculation of movement between buttons that included a time increase when some buttons where occluded by a hand.

The main point is that varying the text corpus or the movement time calculation results in quite different optimized keyboard designs. Nevertheless, the designs do contain some common features. For example, the letters t-h-e are all close to each other because this is a frequent sequence in both text corpuses. Of course, it is an empirical issue to determine whether these design are truly optimized. The optimization is only valid if its underlying assumptions are correct.

DISCUSSION

The optimization technique demonstrated here can be applied to a variety of situations to craft keyboard designs that are optimal for a given set of text and for a given style of interaction with the keyboard. The ability to specialize the keyboard could be useful for situations (such as military and medical environments) where the text to be entered might be quite different than what is used by the general population. Likewise, the ability to consider a variety of movement time calculations allows a keyboard to be crafted for a variety of different situations. For example, a disabled person may want a keyboard that is designed for their specific use and considers the particular characteristics of the person's abilities to interact with the keyboard.

DISCLAIMER

The views, opinions, and/or findings contained in this paper are those of the authors and should not be construed as an official Department of the Army position, policy, or decision unless so designated by other official documentation. Greg Francis was supported by the U.S. Army Aeromedical Research Laboratory under the auspices of the U.S. Army Research Office Scientific Services Program administered by Battelle (Delivery Order 547, Contract No. DAAL03-86-D-001).

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